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Techno-Economic Viability of Tidal Power Generation in the Bight of Benin, Nigerian Coast

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Abstract

Despite its prodigious endowment with ocean renewable energy resources, Nigeria, especially the Southwest industrial hub, suffers massive power problem, leading to numerous socioeconomic and security problems such as high poverty rate, unemployment, collapse of the manufacturing sector, difficulty in doing business, falling human development index, and so on. Over 65% of the population of Southwest Nigeria are residents of the three. Given that about 70% of Southwest Nigeria's population and the nation's industrial hub is concentrated in the coastal states of Lagos, Ogun, and Ondo, with a total of 273Km shoreline, it is imperative to explore and harness ocean renewable energy sources such as tidal energy conversion for mini-grid electrification. A 21-year tidal energy data of the Bight of Benin between 2000 and 2021 was acquired and analysed with a hypothetical 100kW tidal-powered mini-grid in hybrid configuration. The systems were simulated and evaluated with HOMER, Matlab Simulink, Techno-Economic Levelized Cost of Energy (TELCOE), and generic Cost of Energy (COE) computation. Finally, the Techno-Economic Renewable Energy Viability Index (TEREVI) was applied as a confirmatory determinant energy model. Tidal power generation technology has a TEREVI score of 0.65, which is well below the proven threshold due to the relatively low tidal range in the 2 to 4 sea storm class; thus, the recorded mean tidal range is 1.1m with periodic and seasonal spikes which follow quite a similar pattern as the windspeed and wave energy variations. Tables 4.3 and 4.4 show information on the tidal heights and power potentials in the Bay of Benin. The cost of generating electricity is also very high at $0.096153237/kWh from HOMER optimization results, $0.091201/kWh for Matlab simulation results, $0.062248695/kWh for LOCE, and $0.07019/kWh for TELCOE, which makes it uncompetitive at current market rates except for long-term research and development purposes. The low tidal range at the Bight of Benin, coupled with the technological infancy of tidal energy, makes it non – commercially feasible and below the TEREVI threshold.

Keyword: TEREVI, TELCOE, Tidal Power, Tidal Stream Generator, Bight of Benin, Ocean Renewable Energy Technology.

1.0. Introduction

Nigeria is the capital of Africa's energy poverty, with over 90million people without access to electricity, while Sub-Saharan Africa is home to over 90% of the world's population without access to electricity despite decades of advocacy for policy formulations towards addressing energy infrastructure deficits. Since 1999, Nigeria has spent over 30billion aimed at revitalizing or even stabilizing the National Electricity Supply Industry through various public and private initiatives, including bailout of Electricity Distribution Companies (DISCOS) and attempts at revamping the national grid transmission infrastructure, among other things (Adelabu and Akhimien, 2025; Asabor, 2025; Aihie, 2017; Babatunde et al, 2022).

Inadequate power supply and low electricity access in Nigeria and Sub-Saharan Africa is largely responsible for growing insecurity and terrorism in the Sahel regions, high unemployment rates, massive rural urban migration, low agricultural productivity, spiralling exchange rate, and overdependence on foreign goods, collapse of the manufacturing sector, high multi-dimensional poverty, and low Human Development Index (HDI) despite the country and the regions generous endowments with various proven and probable natural resources including ocean renewable energies such as tidal. With a huge population and many underserved and underdeveloped communities located in the littoral zones, tidal energy is a renewable energy source that needs deep studies for possible harnessing in order to address electrification problems in Nigeria. Autonomous mini-grid systems based on locally available renewable energy sources, such as tidal power technology, are a viable approach to solving Sub-Saharan Africa's energy poverty brick by brick. As such, using systems in interconnected hybrid configurations as a bottom-up strategy, given the massive line loss of the national grid and the obsolescence of subpar transmission and distribution equipment, is the best way to go in addressing the lingering energy crisis (Okwori et al, 2025).

A tidal energy conversion system is the technology of electric power generation using the flow gradient between high tides and low tides using a tidal turbine and associated power take-off (PTO) systems. Nigeria has a coastline of 853 km, of which the Bight of Benin is about 50%. Hence, an assessment of the viability of tidal power generation for mini-grid power generation, especially for islets, remote riverine areas, and various unserved communities via mini-grids and embedded generation (Euklidiadas, 2022).

Tidal power generation is a green energy solution to rural electrification with near-zero carbon emissions, with relatively low operating expenditures and a lifecycle of about 50 to 75 years or well over, depending on technology type and maintenance, in addition to being highly predictable and environmentally friendly. Given that the three coastal states of Southwest Nigeria bordering the Bight of Benin, Lagos, Ondo, and Ogun, together account for over 70% of Southwest Nigeria's population, exploring tidal power generation is a strategic approach to head-on addressing power generation Lumley, 2025).

Though most of the world's tidal energy potential is concentrated on the Eurasian west coast with heights up to 5.0m and the United Kingdom having the highest potentials of about 70kW/m average, Sub-Saharan African also holds medium to low potentials with South Africa being the highest at about 45kW/m mean while West African coastlines have varying potentials with significant incremental mean heights from the west in the Bay of Benin to the East in the Bay of Bonny. This in effect, means that the natural tidal potentials are also significantly discretized and localized along various points in the coastlines of Nigeria, both in the Bay of Benin and Bonny, that need to be identified (Elehinafe et al, 2021).

However, the development of ocean renewable energy resources such as tidal and wave energy in particular needs to for good reasons of preserve the pristine beauty of the coastlines be integrated with windbreaks as part of port and harbour structures and associated facilities, in addition to drainage systems, among other possible multi-purpose strategies. Aside from the natural tidal potentials at some sectors, structural designs and developments along coastlines can significantly raise tidal heights above the mean for a given area, such as the development of tidal farms and seawalls or similar efforts at stemming ocean surge. For example, the development of Eko Atlantic City appears to have increased the mean tidal height of the Lagos Bar sector based on empirical observations from sailors and marine experts working or familiar with that axis (Fang et al, 2021; Do-Seong, 2004)

With advances in ocean engineering research and development, tidal power technology is fast becoming a proven technology for even lower tidal heights previously considered unviable for electricity generation due to the growth in learning curve, especially in the last 10years. The Tidal power concept, based on this study, is the bottom-up strategy of installing mini-grid power systems that are interconnected. The Tidal Stream Generator (TSG) technology selected for this study is shown in Figure 3.6 (Vandercruyssen et al, 2024).

The Bay of Benin or Bight of Benin, shown in Figure 3.1, is located between latitude 5.0000° N and longitude 2.1000° E in Africa's west coast, stretching about 640Km from the Cape of St. Paul in Ghana to Akassa at the Nun River Estuary of Bayelsa State. Nigeria's coastline in the Bight of Benin is bordered by six of Nigeria's eight coastal states, namely, Lagos, Ogun, Edo, Delta State, and Bayelsa State. With Nigeria aggressively driving the blue economy agenda, as demonstrated by the recent creation of the Federal Ministry of Marine and Blue Economy, tidal energy is a key ocean renewable energy resource likely to gain the attention of both policymakers and decision makers in both government and private sectors, as well as international donor agencies and development partners (Britannica, 2025).

1.1. Objectives

1.1.1. Acquire tidal energy data for the Bay of Benin, Nigerian Coast

1.1.2. Design a hypothetical tidal-powered hybrid mini-grid system

1.1.3. Evaluate and simulate the hypothetical tidal power mini-grid system using various energy generation costing models

1.1.4. Determine the viability of the tidal power system for the Bight of Benin, Southwest Nigerian coastline.

2. Literature Review

Adebayo et al (2025) assessed the technical, economic, and environmental challenges and benefits of tidal energy generation in Sub-Saharan Africa and exposed the need for an adequate enabling policy framework, creative application of energy solutions, and the need to deliberate work towards the development of energy resources. In addition, there is a need for aggressive research and development efforts coupled with adequate funding and political will to optimize ocean renewable energy resources, given the significant capital commitment involved.

Adebayo et al (2025) analyzed the issues and challenges surrounding the lack of adoption of tidal power generation in the Sub-Saharan African power mix despite natural endowment. They concluded that tidal power generation is viable via public and private partnership in the technical, financial, and political aspects of development as critical success factors for tidal energy systems to gain a foothold in the region. This, according to the research, requires multi-dimensional and multi-layered efforts to work in concert to make significant progress.

Euklidiadas (2022) analyzed tidal energy generation resources and infrastructure. The report highlighted the impact of tidal generators on the coastline and the associated vulnerability and environmental issues affecting the flora and fauna. To this, there has to be both efforts at mitigation and reaching a compromise between the environmental sanctity of the oceanfront and energy solutions, both of which present strong, legitimate environmental, social, technical, economic, and sustainability justifications.

Elehinafe et al (2021) assessed the status of ocean renewable energy potentials in Nigeria's future energy mix, with Lagos Bar and the Bight of Bonny coastline notably Calabar sectors having the highest, with a mean tidal range well over 2m, while the general heights for Nigeria's coastlines range between 1.2m and 3.5m. However, the biggest challenge, according to their studies, is the dearth of research efforts, given that Nigeria has only one government parastatal involved in marine research. Hence, significant efforts need to be geared towards advancing research and development on tidal energy, along with other ocean renewable energy technologies, to commence possible exploitation.

3. Tidal Power Principles, Technologies, and Methods

Tidal power system is the process of generating electricity from the energy of water current due to difference in tidal height or tidal gradient between the upstream and downstream of a PTO or Tidal Energy Conversion system such as a tidal barrage energy to drive a turbine in run – of – flow using velocity of water or reservoir mode using potential energy of water from high tides. Tidal energy is caused by the gravitational attractions between planetary bodies in the solar system and, more importantly, the gravitational pulls between the Earth, the moon, and the sun, resulting in the disturbance and variation of ocean water currents in direction with Earth's rotation. Thus, Tides are long–period waves rolling around the Earth due to the gravitational push and pull between the Earth, the sun, and the moon, causing back-and-forth motion of the ocean as the Earth daily rotates about its axis and yearly revolves around the sun, while the month monthly revolves around the Earth as its satellite.

Since the earth is not perfectly spherical, the relative motions between the sun, the moon, and the earth results in different types of tides in the course of completing revolutions and rotations which includes: spring(king) tides, neap tides, high and low tides, (NOAA, 2023) with 3 tidal cycles: semi – diurnal, diurnal, and mixed tides. Spring tides also called perigean tide or king tides are independent of season and occur twice per lunar month year round during which time the sun, the earth, and the moon are in complete or partial alignment resulting higher mean tidal ranges (higher high tides and lower low tides) due a combination earth – sun and earth – moon gravitational pull and this occurs at full moon(the period in which the moon appears darker because it is between sun and moon) or new moon(period in which the moon appears new because it is between earth and sun).

Neap tides occur when the sun and the moon are spatially perpendicular to each other, thereby having the earth – sun gravitational pull and earth – moon gravitational pull partially canceling out each other resulting in moderate tidal ranges since high tides become a little lower than mean high tide values and low tides become a little higher than mean low tide values. Neap tides occur 7 days following a spring tide occurrence during the first and third quarter months at half-moon (NOAA, 2023).

Diurnal tidal regime as experienced in some oceans and seas is a cycle of one low tide and one high tide per occurring in a lunar day while semi – diurnal tide being the most common for most coasts is a two – cycle of two fairly equal high and low tides occurring in a lunar day with low to hide tide transition lasting 12hours 12minutes. Mixed tide is two cycle of low and high tides of different heights occurring in a lunar day.

Since tide is a water depth adjuster, meteorological tides are tidal regimes caused by non – planetary forces but by weather elements such as atmospheric pressure, temperature, and rainfall etc. instead of sun and moon's gravitational pull resulting in the rise or fall of ocean water levels. Actually, the meteorological tide arising from storm or rainfall is called storm tide. Rip tides are tidal regimes due to high water current resulting from the narrowing of inland to sea water flow by natural tide flows at estuaries, deltas and similar headlands.

Rip tide is the current of water draining from irregular or non – uniformly shaped coastline in the path of least resistance following differential depths and sand depositions along the shoreline. The current of water discolorored by algae is referred to as brown or red tide or whatever the respective colour of its physical appearance just like black tide is due to oil flow on water surface.

High tide is the maximum height of a high tidal cycle while low tide is the minimum height of a low tide cycle with the difference between high and low tide called tidal range. Flood tide is the technical term for a rising tide while Ebb tide refers to a falling tide. Slack tide is the tide at which water current is at minimum typical at low waters and at high waters. Nwaokocha et al (2015) based on a 10 – year evaluation of tidal height across Nigeria shows a progressive decrease in maximum height from East to Western Nigerian coast from Calabar, 3.07m to Lagos 1.3m which remain fairly constant without significant changes yearly.

Tidal power plant requires more favourable sites in terms of the tidal range or the stream speed which is greatly determined by the bathymetric topography and coast like structure of the water and headlands as to supporting higher water flow speed from areas of higher ocean floors areas of lower floors thereby establishing suitable gradient for power generation. Typically, tidal flow speed above 2m/s and heights above 7m/s are desired for commercially viable exploitation. However, choice of PTO system as well as advances in technology is lowering the natural requirements.

Tidal power conversion technologies are chosen based on the tidal power potential of a given site. Though limited sites for tidal power harnessing are available, technological advancement is fast extending the viability of even very low head tides through various optimization techniques. Popular existing tidal power technologies include: Tidal barrage, Tidal Stream, dynamic tidal power (DTP), and tidal lagoon.

Tidal barrage technology is based on strategic walling of the water especially across tidal estuaries between high and low tides with a narrowed cross section of underwater channels or gats with hydraulic turbines similar in design with wind turbines installed to generate electricity as the water flows from hide to low tides as well as in reverse direction of flow because water current changes direction after every 12 hours or thereabout (EpicVin, 2025).

Tidal stream generator is based on the installation of wind–turbine–like hydraulic turbines to take advantage of the current of water between tides to generate electricity. The tidal stream generator is installed as a compact assembly with turbine, generator, and supporting structure, usually in semi–semi-submerged configuration (PNNL, 2016).

DTP technology optimally integrates both potential and kinetic energy of the water and is based on the construction of extensively long dams from coastal front to far into the water, say up to 100Km without any enclosure with progressive tidal phase differentials resulting in significant water gradient even in shallow coastal areas featuring strong oscillating parallel currents by means of Lupus Pulse Drum (PSD) using hydro atmospheric concept via water pistons pushing of pulling measured volume of water into a rotary air actuator system. DTP technology in effects makes lower coastal heads like obtains in Southwest Nigeria coasts viable for commercial tidal power generation.

Tidal Lagoon is based the creation of artificial reservoirs similar to tidal barrage with circular retaining walls embedded with hydraulic turbines to capture and generate electricity using the potential energy of the trapped waters with or without pump. Thus enabling excess renewable energy such as solar or wind to be used to pump more waters into the reservoir to flatten out energy demand and supply in times of grid shortage fit for baseload given its dispatchability, predictability, storability and high capacity factor (PNNL, 2016).

This technology enables even low tidal potential coastal areas and lagoons to generated electricity and is different from tidal barrage on by the fact that it is an artificial water trap unlike tidal barrage that has preexisting eco system.

Though tidal and wave energy are still very much at their technological infancy just like other ocean energy sources and the paucity of research fund has been very challenging compared to the huge attention given by governments and financial corporations to other renewable sources like solar, wind, and hydro, tidal energy development has grown in leaps and bounds especially in the last 15years with huge breakthrough and ongoing experimentations that serious minded national and regional governments the world over along littoral zones are fast keying in with various pilot projects especially in Europe, Asia and North America.

Notable tidal power projects recently developed across the world includes the 254MW Sihwa Lake Tidal Power Station in South Korea which came online 2011 at a total cost of $560million, that is about $2.2million/MW; which is competitive with the installation cost of most established renewable energy sources like wind and solar. The 254MW generation either marginally meets or exceeds the average grid demands of less industrialized southwest states like Ondo, Osun and Ekiti State, which is quite a whole lot.

A small tidal power project worth noting is the 2MW Orkney Tidal Power Station off the coast of Orkney in Scotland, using the SR2000 tidal energy conversion system, using a surface floating boat-like platform holding its blade's rotor, unlike the typical wind turbine, like popular PTO. The plant came onstream as a pilot project in 2017 with bigger projects to follow.

With new technologies making even low tidal heights economically viable for power generation in commercial scale, this points to the need for concerned governments, ministries, departments and agencies to key into pilot projects for Nigeria to commence the development of ocean energy resources at least in pilot phase like the 360Km coastal line of southwest Nigeria and other locations to not just solve the country's power problems but to also be at the frontiers of developing these technologies and accessing the value added benefits of associated technoeconomic opportunities and related technologies.

Figures 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6 show the Bay of Benin, tidal mini-grid viability process workflow, tidal hybrid mini-grid system design, bottom-up hybrid power system, Tidal Stream Generator powertrain, and Tidal Stream Generator concept design.

Tidal power P_T per square meter on a coastal front based on hydro turbine PTO system is calculated very similarly to hydropower and thus given by the following equation given the acceleration due to gravity at the point, water density, $\boldsymbol{\rho}$; tidal height, H; and water flowrate across the barrage gradient to hydraulic turbine blade, $\dot{Q}$:

$$P_T = C_p \boldsymbol{\rho g H \dot{Q}} \qquad \text{.................................3.1}$$

Or in situations of speed flow through a turbine, given the tidal current velocity as V is high with negligible height for a tidal turbine, we have:

$$P_T = 0.5C_pV^2\boldsymbol{\rho Q} \qquad \text{………………………….3.2}$$

Where CP is the coefficient of power and a product of the turbine blading efficiency, η_T, and the generator efficiency η_G. Hence,

$$C_P = \eta_T\eta_G \qquad \text{…………………………..3.3}$$

Therefore, the instantaneous tidal power density is expressed as follows, given the cross-sectional area of the tidal turbine blade or device:

$$\frac{P_T}{A_T} = 0.5\rho V^3 \qquad \text{…..……………………….3.4}$$

Based on works by Garret and Cummins (2001), the maximum derivable power from a tidal bay to the open ocean can be given by the following equation, given the surface area of the bay, A; the amplitude of the dominant tidal constituent, Z; and the frequency of the dominant tidal constituent, f. Thus:

$$P_T = 0.24C_P\boldsymbol{\rho gAfZ^2} \qquad \text{…………………………3.5}$$

Fig. 3.1: Aerial view of the Bay of Benin

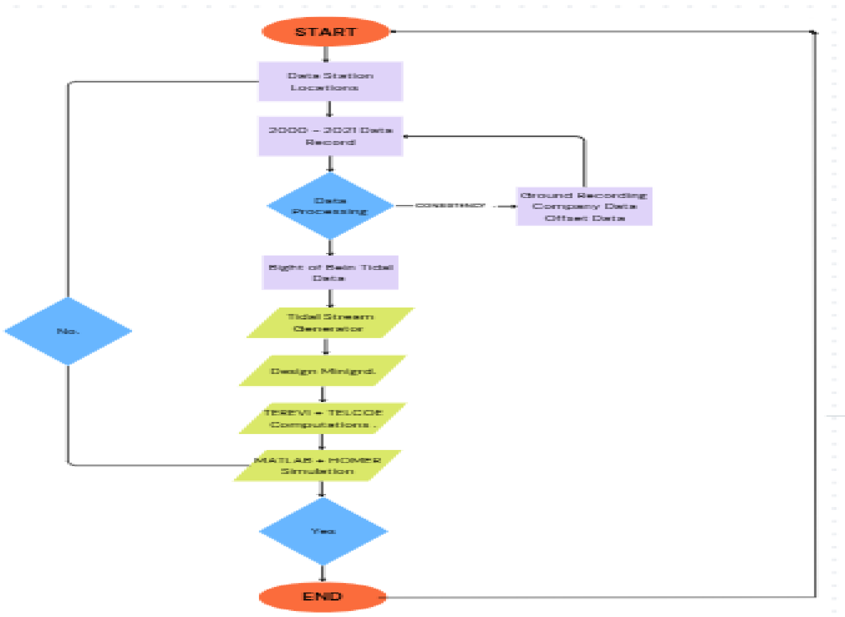

Fig. 3.2: Tidal power mini-grid viability process flow diagram

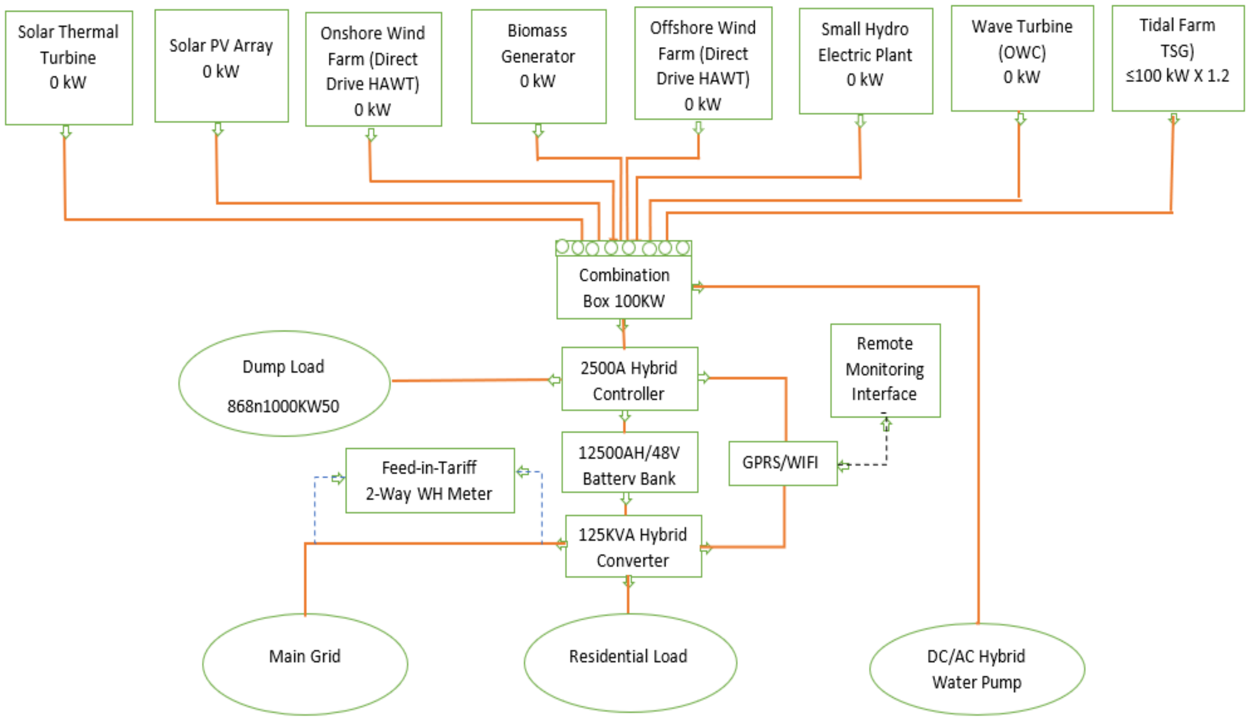

Fig. 3.3: Tidal–powered mini-grid in hybrid configuration mode

Fig. 3.4: Bottom-up hybrid mini-grid in interconnected mode

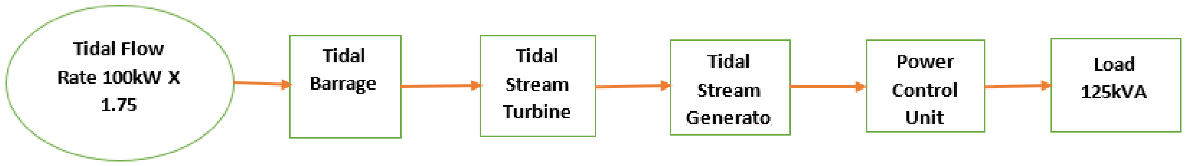

Fig. 3.5: TSG Tidal powertrain configuration

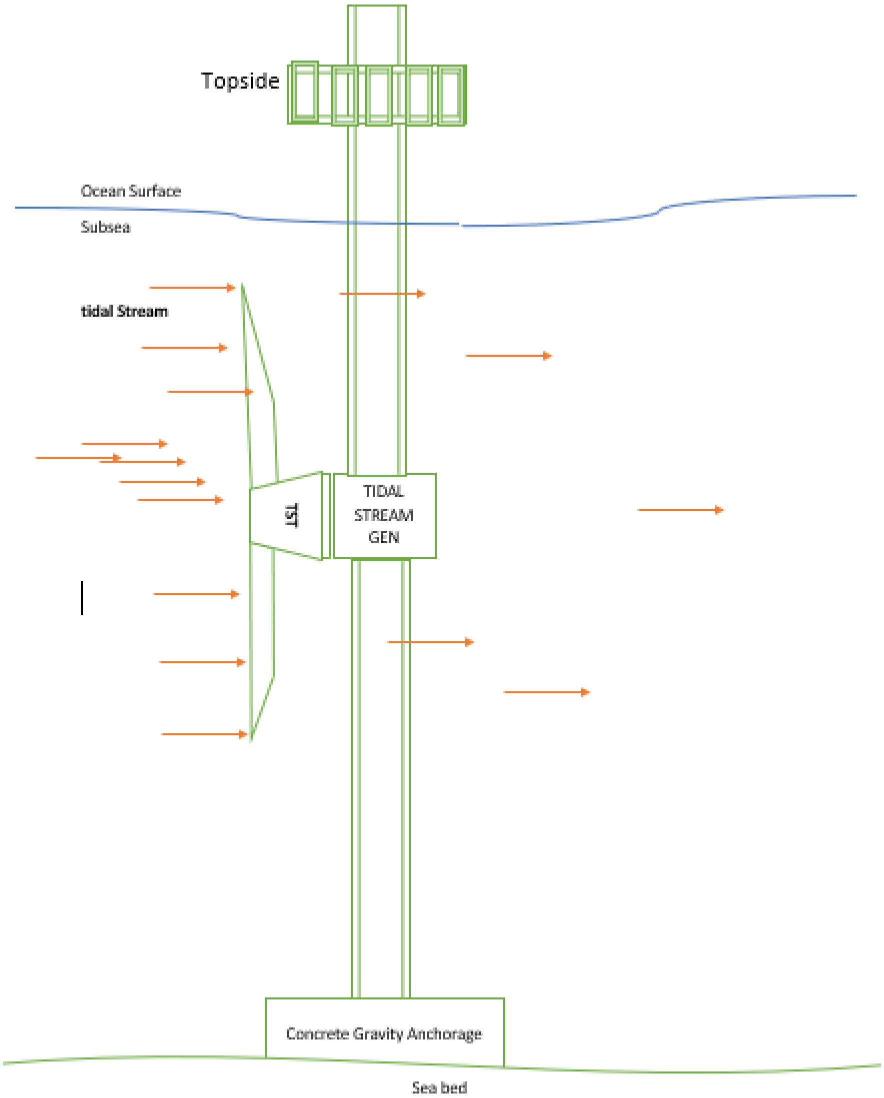

Fig. 3.6: TSG Tidal power generation concept design

4.0. Bay of Benin Tidal Energy Data

The Gulf of Guinea, which is the part of the Atlantic Ocean to which both the Bight of Benin and the Bight of Bonny are collectively hosted is characterized by relatively low wave swells and tidal heights ranging between 0.1m and 2.0m propagated by the strong westerly winds from the Southern Atlantic Ocean called Roaring Forties between Latitude 40◦S and 50◦S (Zhou et al, 2021).

AVERAGE TIDAL 2018 - 2021 OCEAN TIDAL DATA OF SOUTH - WEST NIGERIA COAST						
	2018	**2019**	**2020**	**2021**	**AVERAGE**	
JANUARY	1.587096774	1.570967742	1.525806452	1.529032258	1.561290323	High Tide
	0.403225806	0.435483871	0.448387097	0.477419355	0.429032258	Low Tide
	1.183870968	1.135483871	1.077419355	1.051612903	1.132258065	Tidal Range
FEBRURY	1.525	1.532142857	1.521428571	1.507142857	1.526190476	High Tide
	0.471428571	0.425	0.442857143	0.467857143	0.446428571	Low Tide
	1.053571429	1.107142857	0.974193548	1.039285714	1.044969278	Tidal Range
MARCH	1.496774194	1.483870968	1.461290323	1.496774194	1.480645161	High Tide
	0.412903226	0.435483871	0.438709677	0.429032258	0.429032258	Low Tide
	1.083870968	1.1	1.022580645	1.067741935	1.068817204	Tidal Range
APRIL	1.476666667	1.463333333	1.44516129	1.464516129	1.46172043	High Tide
	0.383333333	0.396666667	0.4	0.374193548	0.393333333	Low Tide
	1.093333333	1.066666667	1.04516129	1.090322581	1.068387097	Tidal Range
MAY	1.44516129	1.453333333	1.441935484	1.45483871	1.446810036	High Tide
	0.335483871	0.326666667	0.338709677	0.338709677	0.333620072	Low Tide
	1.109677419	1.126666667	1.103225806	1.116129032	1.113189964	Tidal Range
JUNE	1.426666667	1.43	1.446666667	1.423333333	1.434444444	High Tide
	0.353333333	0.293333333	0.32	0.326666667	0.322222222	Low Tide
	1.073333333	1.136666667	1.126666667	1.096666667	1.112222222	Tidal Range
JULY	1.435483871	1.435483871	1.433333333	1.42	1.434767025	High Tide
	0.306451613	0.325806452	0.3	0.323333333	0.310752688	Low Tide
	1.129032258	1.109677419	1.133333333	1.096666667	1.124014337	Tidal Range
AUGUST	1.44516129	1.451612903	1.435483871	1.448387097	1.444086022	High Tide
	0.319354839	0.335483871	0.396774194	0.367741935	0.350537634	Low Tide
	1.125806452	1.116129032	1.038709677	1.080645161	1.093548387	Tidal Range
SEPTEMBER	1.464516129	1.456666667	1.470967742	1.443333333	1.464050179	High Tide
	0.390322581	0.39	0.412903226	0.41	0.397741935	Low Tide
	1.074193548	1.066666667	1.058064516	1.033333333	1.066308244	Tidal Range
OCTOBER	1.5	1.506451613	1.516129032	1.470967742	1.507526882	High Tide
	0.422580645	0.419354839	0.435483871	0.438709677	0.425806452	Low Tide
	1.077419355	1.087096774	1.080645161	1.032258065	1.08172043	Tidal Range
NOVEMBER	1.541935484	1.536666667	1.548387097	1.570967742	1.542329749	High Tide
	0.433333333	0.443333333	0.441935484	0.422580645	0.43953405	Low Tide

	1.11	1.093333333	1.106451613	1.148387097	1.103261649	Tidal Range
DECEMBER	1.580645161	1.567741935	1.54516129	1.580645161	1.564516129	High Tide
	0.458064516	0.467741935	0.438709677	0.438709677	0.45483871	Low Tide
	1.122580645	1.1	1.106451613	1.141935484	1.109677419	Tidal Range

Table 4.1: Mean tidal heights in the Bay of Benin

2R Renewable Energy Reserve in South–West Nigeria		
S/N	Renewable Energy Resources	AVERAGE Potential (MWH) MW
1	Solar (PV + CSP)	135,502,198.5
2	Onshore Wind	2,276,644,673.1456
3	Offshore Wind	1,886,924,786,356.8
4	Biomass	3,097,889,859.319
5	Micro Hydro	6,622,560,000
6	Wave	1,269,898,875
7	Tidal	1,893,751,171.875
	Total	1,902,221,033,134.64

Table 4.2: Probable renewable energy resources in southwest Nigeria

Tidal power generation technology has a TEREVI score of 0.64, which is below the proven threshold due to the relatively low tidal range in the 2 to 4 sea storm class; thus, the recorded mean tidal range is 1.1m with periodic and seasonal spikes which follow quite a similar pattern as the windspeed and wave energy variations.

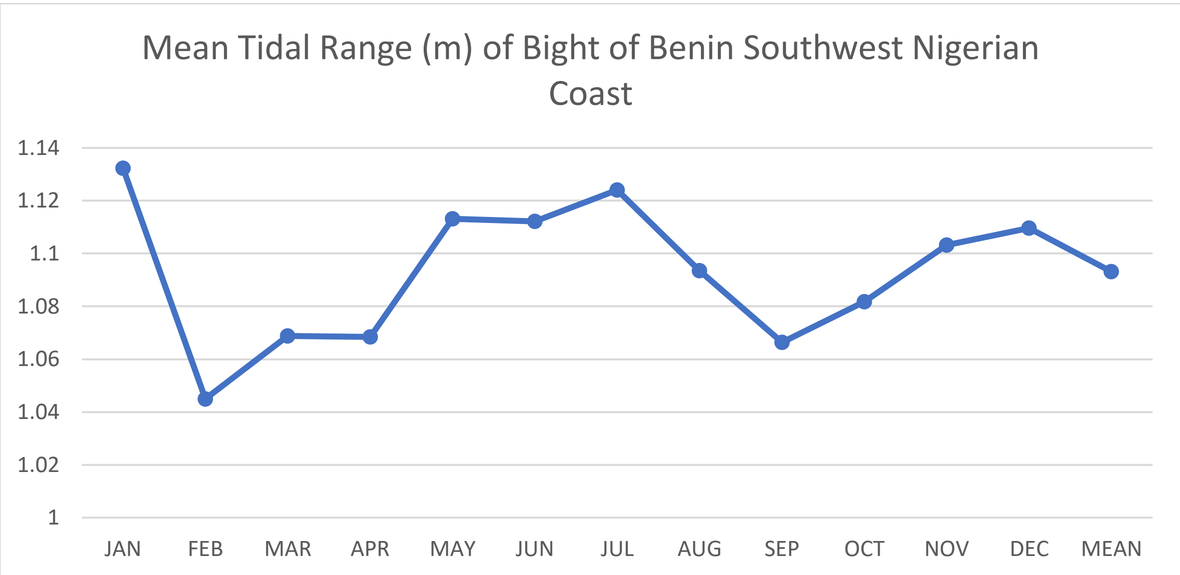

Fig. 4.1: mean tidal range in the Bay of Benin

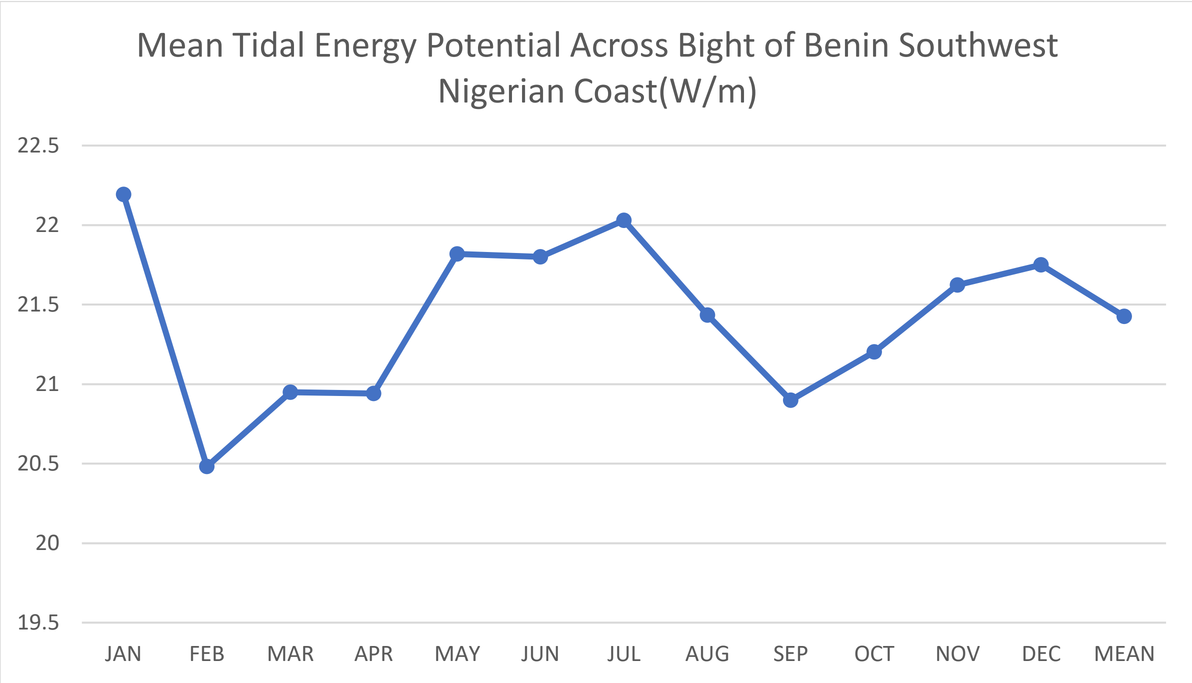

Fig. 4.2: mean tidal power potential in the Bight of Benin, Nigerian coast

Tables 4.1 and 4.2 show the tidal energy data of the Bight of Benin as conservative information taken as the mean of various designated stations for representative information, even distributed across its Nigerian coastal stretch. Fig 4.1 and 4.2 shows the mean tidal heights and power potentials across the Bay of Benin.

The Gulf of Guinea, which is the part of the Atlantic Ocean to which both the Bight of Benin (whose height is shown in table 3.10) and the Bight of Bonny are collectively hosted is characterized by relatively low wave swells and tidal heights ranging between 0.1m and 2.0m propagated by the strong westerly winds from the Southern Atlantic Ocean called Roaring Forties between Latitude 40◦S and 50◦S (Zhou et al, 2021).

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Due to the fact that the earth is not perfectly spherical in shape, the relative motions between the sun, the moon, and the earth results in different types of tides in the course of completing revolutions and rotations which includes: spring(king) tides, neap tides, high and low tides, (NOAA, 2023) with 3 tidal cycles: semi – diurnal, diurnal, and mixed tides.

Spring tides also called perigean tide or king tides are independent of season and occur twice per lunar month year round during which time the sun, the earth, and the moon are in complete or partial alignment resulting higher mean tidal ranges (higher high tides and lower low tides) due a combination earth – sun and earth – moon gravitational pull and this occurs at full moon(the period in which the moon appears darker because it is between sun and moon) or new moon(period in which the moon appears new because it is between earth and sun).

Neap tides occur when the sun and the moon are spatially perpendicular to each other thereby having the earth – sun gravitational pull and earth – moon gravitational pull partially canceling out each other resulting in moderate tidal ranges since high tides become a little lower than mean high tide values and low tides become a little higher than mean low tide values. Neap tides occur 7 days following a spring tide occurrence during the first and third quarter months at half-moon (NOAA, 2023).

Diurnal tidal regime as experienced in some oceans and seas is a cycle of one low tide and one high tide per occurring in a lunar day while semi – diurnal tide being the most common for most coasts is a two – cycle of two fairly equal high and low tides occurring in a lunar day with low to hide tide transition lasting 12hours 12minutes. Mixed tide is two cycle of low and high tides of different heights occurring in a lunar day.

Since tide is a water depth adjuster, meteorological tides are tidal regimes caused by non – planetary forces but by weather elements such as atmospheric pressure, temperature, and rainfall etc. instead of sun and moon's gravitational pull resulting in the rise or fall of ocean water levels. Actually, the meteorological tide arising from storm or rainfall is called storm tide. Rip tides are tidal regimes due to high water current resulting from the narrowing of inland to sea water flow by natural tide flows at estuaries, deltas and similar headlands.

Rip tide is the current of water draining from irregular or non – uniformly shaped coastline in the path of least resistance following differential depths and sand depositions along the shoreline. The current of water discolorored by algae is referred to as brown or red tide or whatever the respective colour of its physical appearance just like black tide is due to oil flow on water surface.

High tide is the maximum height of a high tidal cycle while low tide is the minimum height of a low tide cycle with the difference between high and low tide called tidal range. Flood tide is the technical term for a rising tide while Ebb tide refers to a falling tide. Slack tide is the tide at which water current is at minimum typical at low waters and at high waters.

Nwaokocha et al (2015) based on a 10 – year evaluation of tidal height across Nigeria shows a progressive decrease in maximum height from East to Western Nigerian coast from Calabar, 3.07m to Lagos 1.3m which remain fairly constant without significant changes yearly.

Tidal power plant requires more favourable sites in terms of the tidal range or the stream speed which is greatly determined by the bathymetric topography and coast like structure of the water and headlands as to supporting higher water flow speed from areas of higher ocean floors to areas of lower floors thereby establishing suitable gradient for power generation. Typically, tidal flow speed above 2m/s and heights above 7m/s are desired for commercially viable exploitation. However, choice of PTO system as well as advances in technology is lowering the natural requirements.

Tidal power conversion technologies are chosen based on the tidal power potential of a given site. Though limited sites for tidal power harnessing are available, technological advancement is fast extending the viabilities of even very low head tides through various optimization techniques. Popular existing tidal power technologies include: Tidal barrage, Tidal Stream, dynamic tidal power (DTP), and tidal lagoon.

Tidal barrage technology is based on strategic walling of the water especially across tidal estuaries between high and low tides with a narrowed cross sections of underwater channels or gats with hydraulic turbines similar in design with wind turbines installed to generate electricity as the water flows from hide to low tides as well as in reverse direction of flow due to the fact that water current changes direction after every 12 hours or thereabout(Robert, 2007).

Tidal stream generator is based on the installation of wind – turbine like hydraulic turbines to take advantage of the current of waters between tides to generate electricity. The tidal stream generator is installed as a compact assembly with turbine, generator and supporting structure usually in semi – submerged configuration (PNNL, 2016).

DTP technology optimally integrates both potential and kinetic energy of the water and is based on the construction of extensively long dams from coastal front to far into the water, say up to 100Km without any enclosure with progressive tidal phase differentials resulting in significant water gradient even in shallow coastal areas featuring strong oscillating parallel currents by means of Lupus Pulse Drum (PSD) using hydro atmospheric concept via water pistons pushing of pulling measured volume of water into a rotary air actuator system. DTP technology in effects makes lower coastal heads like obtains in Southwest Nigeria coasts viable for commercial tidal power generation.

Tidal Lagoon is based the creation of artificial reservoirs similar to tidal barrage with circular retaining walls embedded with hydraulic turbines to capture and generate electricity using the potential energy of the trapped waters with or without pump. Thus, enabling excess renewable energy such as solar or wind to be used to pump more waters into the reservoir to flatten out energy demand and supply in times of grid shortage fit for baseload given its dispatchability, predictability, storability and high capacity factor (PNNL, 2016).

This technology enables even low tidal potential coastal areas and lagoons to generated electricity and is different from tidal barrage on by the fact that it is an artificial water trap unlike tidal barrage that has preexisting eco system.

Though tidal and wave energy are still very much at their technological infancy just like other ocean energy sources and the paucity of research fund has been very challenging compared to the huge attention given by governments and financial corporations to other renewable sources like solar, wind, and hydro, tidal energy development has grown in leaps and bounds especially in the last 15years with huge breakthrough and ongoing experimentations that serious minded national and regional governments the world over along littoral zones are fast keying in with various pilot projects especially in Europe, Asia and North America.

Notable tidal power projects recently developed across the world include the 254MW Sihwa Lake Tidal Power Station in South Korea, which came online in 2011 at a total cost of $560million, that is about $2.2million/MW, which is competitive with the installation cost of most established renewable energy sources like wind and solar. The 254MW generation either marginally meets or exceeds the average grid demands of less industrialized southwest states like Ondo, Osun, and Ekiti State, which is quite a whole lot.

A small tidal power project worth noting is the 2MW Orkney Tidal Power Station off the coast of Orkney in Scotland, using the SR2000 tidal energy conversion system, which uses a surface floating boat-like platform holding its blade's rotor, unlike the typical wind turbine like popular PTO. The plant came onstream as a pilot project in 2017 with bigger projects to follow.

With new technologies making even low tidal heights economically viable for power generation in commercial scale, this points to the need for concerned governments, ministries, departments and agencies to key into pilot projects in order for Nigeria to commence the development of ocean energy resources at least in pilot phase like the 360Km coastal line of southwest Nigeria and other locations in order to not just solve the country's power problems but to also be at the frontiers of developing these technologies and accessing the value added benefits of associated technoeconomic opportunities and related technologies.

The Gulf of Guinea, which is the part of the Atlantic Ocean to which both the Bight of Benin and the Bight of Bonny are collectively hosted is characterized by relatively low wave swells and tidal heights ranging between 0.1m and 2.0m propagated by the strong westerly winds from the Southern Atlantic Ocean called Roaring Forties between Latitude 40◦S and 50◦S (Zhou et al, 2021).

AVERAGE TIDAL 2018 - 2021 OCEAN TIDAL DATA OF SOUTH-WEST NIGERIA COAST						
	2018	2019	2020	2021	AVERAGE	
JANUARY	1.587097	1.570968	1.525806	1.529032	1.56129	High Tide
	0.403226	0.435484	0.448387	0.477419	0.429032	Low Tide
	1.183871	1.135484	1.077419	1.051613	1.132258	Tidal Range
FEBRURY	1.525	1.532143	1.521429	1.507143	1.52619	High Tide

	0.471429	0.425	0.442857	0.467857	0.446429	Low Tide
	1.053571	1.107143	0.974194	1.039286	1.044969	Tidal Range
MARCH	1.496774	1.483871	1.46129	1.496774	1.480645	High Tide
	0.412903	0.435484	0.43871	0.429032	0.429032	Low Tide
	1.083871	1.1	1.022581	1.067742	1.068817	Tidal Range
APRIL	1.476667	1.463333	1.445161	1.464516	1.46172	High Tide
	0.383333	0.396667	0.4	0.374194	0.393333	Low Tide
	1.093333	1.066667	1.045161	1.090323	1.068387	Tidal Range
MAY	1.445161	1.453333	1.441935	1.454839	1.44681	High Tide
	0.335484	0.326667	0.33871	0.33871	0.33362	Low Tide
	1.109677	1.126667	1.103226	1.116129	1.11319	Tidal Range
JUNE	1.426667	1.43	1.446667	1.423333	1.434444	High Tide
	0.353333	0.293333	0.32	0.326667	0.322222	Low Tide
	1.073333	1.136667	1.126667	1.096667	1.112222	Tidal Range
JULY	1.435484	1.435484	1.433333	1.42	1.434767	High Tide
	0.306452	0.325806	0.3	0.323333	0.310753	Low Tide
	1.129032	1.109677	1.133333	1.096667	1.124014	Tidal Range
AUGUST	1.445161	1.451613	1.435484	1.448387	1.444086	High Tide
	0.319355	0.335484	0.396774	0.367742	0.350538	Low Tide
	1.125806	1.116129	1.03871	1.080645	1.093548	Tidal Range
SEPTEMBER	1.464516	1.456667	1.470968	1.443333	1.46405	High Tide
	0.390323	0.39	0.412903	0.41	0.397742	Low Tide
	1.074194	1.066667	1.058065	1.033333	1.066308	Tidal Range
OCTOBER	1.5	1.506452	1.516129	1.470968	1.507527	High Tide
	0.422581	0.419355	0.435484	0.43871	0.425806	Low Tide
	1.077419	1.087097	1.080645	1.032258	1.08172	Tidal Range
NOVEMBER	1.541935	1.536667	1.548387	1.570968	1.54233	High Tide
	0.433333	0.443333	0.441935	0.422581	0.439534	Low Tide
	1.11	1.093333	1.106452	1.148387	1.103262	Tidal Range
DECEMBER	1.580645	1.567742	1.545161	1.580645	1.564516	High Tide
	0.458065	0.467742	0.43871	0.43871	0.454839	Low Tide
	1.122581	1.1	1.106452	1.141935	1.109677	Tidal Range

Table 4.3: Mean Tidal Data of the Bight of Benin, Nigeria Coast

Month	High Tide (m)	Low Tide(m)	Tidal Range (m)	Power (kW/m)
JAN	1.56129	0.42903	1.13226	6538.242
FEB	1.52619	0.44643	1.04497	5568.997
MAR	1.48065	0.42903	1.06882	5826.086
APRIL	1.46172	0.39333	1.06839	5821.399
MAY	1.44681	0.33362	1.11319	6319.879
JUN	1.43444	0.32222	1.11222	6308.893
JUL	1.43477	0.31075	1.12401	6443.378
AUG	1.44409	0.35054	1.09355	6098.821
SEP	1.46405	0.39774	1.06631	5798.765
OCT	1.50753	0.42581	1.08172	5967.603
NOV	1.54233	0.43953	1.10326	6207.654
DEC	1.56452	0.45484	1.10968	6280.054

Table 4.4: Mean Tidal power regime in the Bight of Benin

5.0. Discussion of Results

Tidal power generation technology has a TEREVI score of 0.65, which is well below the proven threshold due to the relatively low tidal range in the 2 to 4 sea storm class; thus, the recorded mean tidal range is 1.1m with periodic and seasonal spikes which follow quite a similar pattern as the windspeed and wave energy variations. Tables 4.3 and 4.4 show information on the tidal heights and power potentials in the Bay of Benin.

The cost of generating electricity is also very high at \$0.096153237/kWh from HOMER optimization results, \$0.091201/kWh for Matlab simulation results, \$0.062248695/kWh for LOCE, and \$0.07019/kWh for TELCOE, which makes it uncompetitive at current market rates except for long-term research and development purposes. The low tidal range at the Bight of Benin, coupled with the technological infancy of tidal energy, makes it non – commercially feasible and below the TEREVI threshold.

Figures 5.1, 5.2, 5.3, 5.4, and 5.5 show the variations in tidal heights, power potentials, and regimes in the Bight of Benin, Nigerian coast in the Gulf of Guinea. This is very indicative of the general benign metocean conditions of the West African Atlantic Ocean.

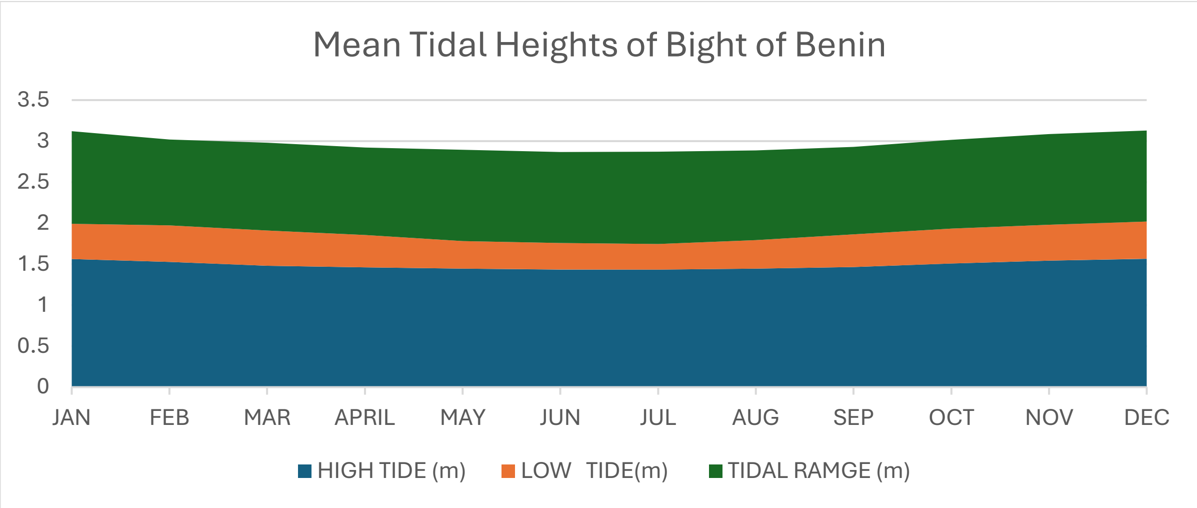

Fig. 5.1: Mean tidal range, high, and low heights at the Bight of Benin

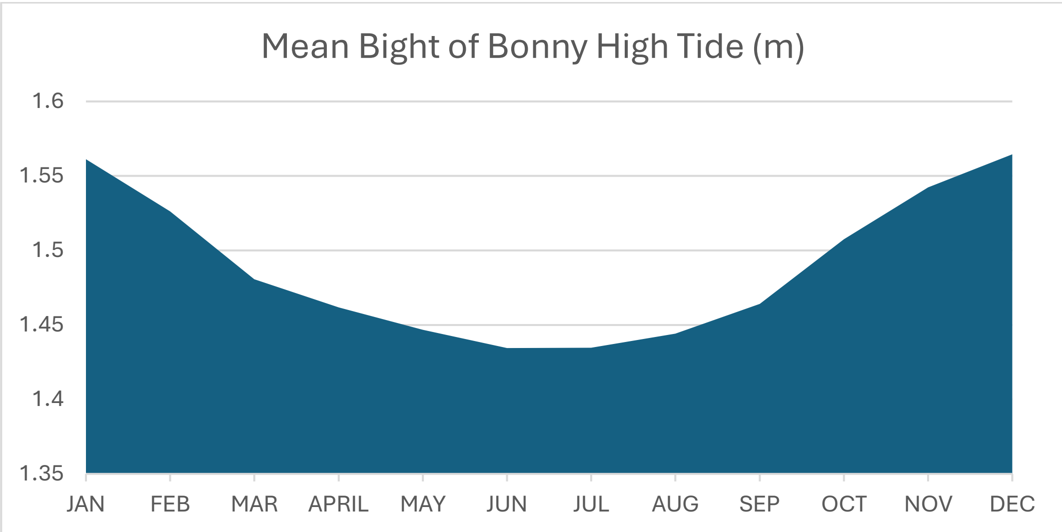

Fig. 5.2: Mean high tide regime at the Bight of Benin

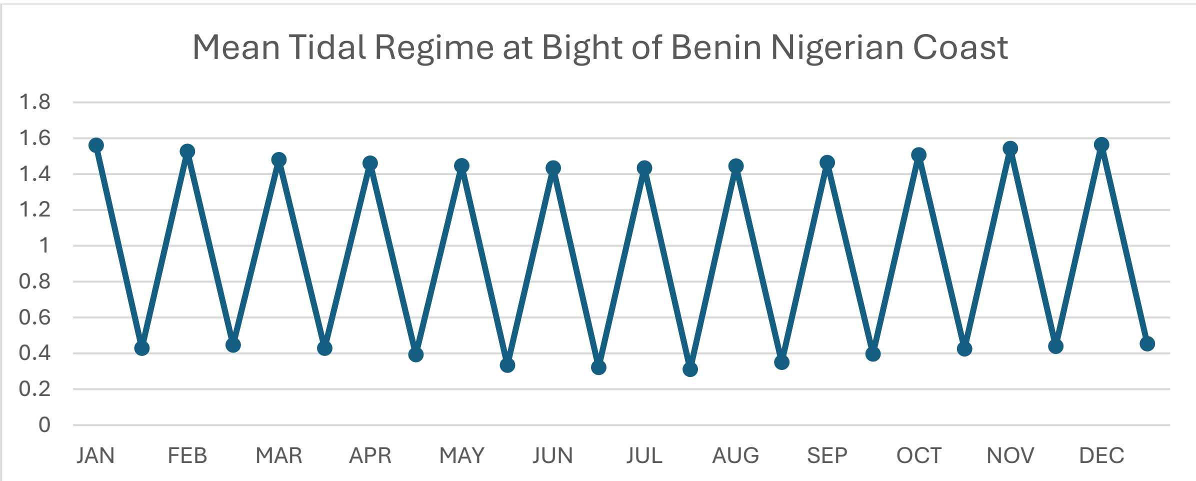

Fig. 5.3: Mean tidal regime at the Bight of Benin

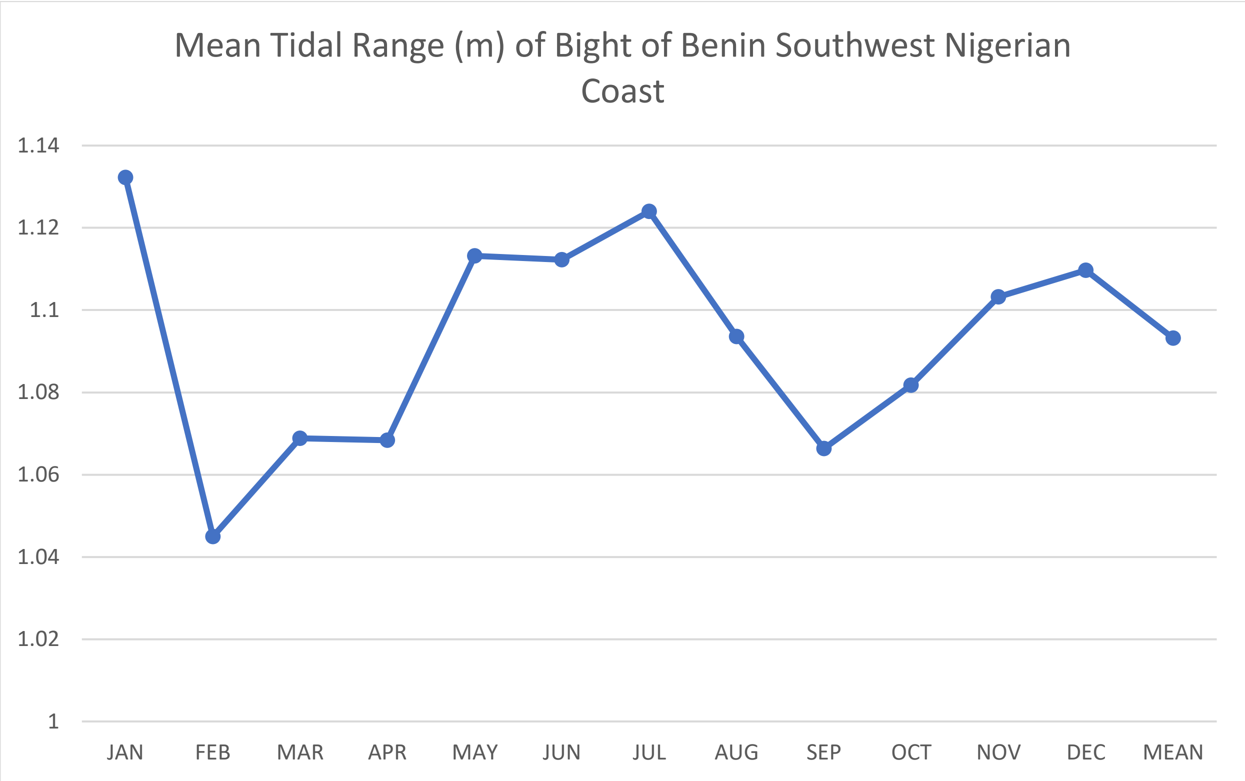

Fig. 5.4: Mean tidal range at Bight of Benin

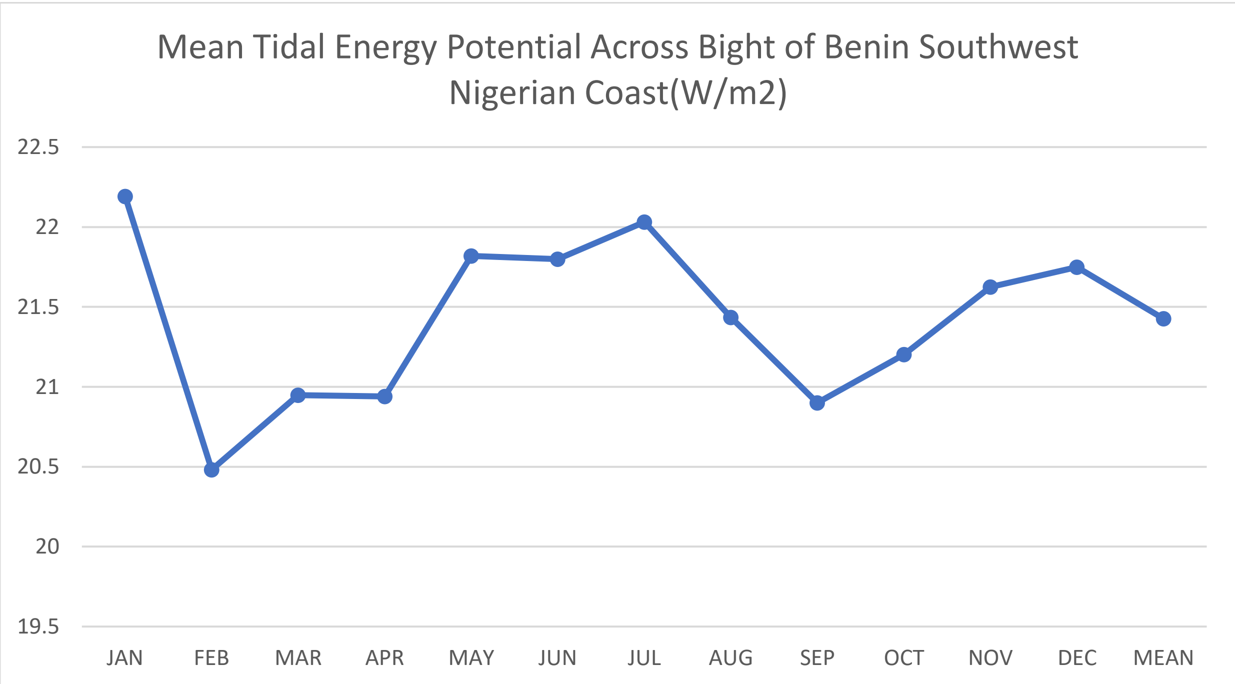

Fig. 5.5: Tidal power potential at the Bight of Benin

Conclusion

Tidal power is a very promising power generation source, especially with the careful selection of technology type, size, and development site, given the limited natural potential with respect to the current technology level. The application of tidal power in small-scale pilot projects, as demonstrated in this study, is a very strategic means of tapping into the medium and long-term potentials and advantages the technology presents in order to scale up as a base load power source once the tidal power research and development comes of age.

Given its durability, reliability, and predictivity, tidal power research and development needs to be stepped up by Federal, States, and Local Governments in coastal areas as well as research institutions to optimize high potential sectors of the littoral zones for the provision of mini-grid electrification to rural coastal villages and unmotorable settlements as a demonstration project for medium- and long-term commercial project planning and development. The need to invest in tidal power is key to harnessing the value migration inherent in the blue economy as a national priority.

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